Appendix A

The following document by:

Glosten
The Glosten Associates, Incorporated
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Mr. John Kratochvil
International Trade and Transportation Manager
Oregon Department of Agriculture
Agricultural Development and Marketing Division
1207 NW Naito Parkway, Suite 104
Portland, Oregon 97209-2832

Subject: Barge Transportation Study

Reference: Your letter to Bill Hurley, President, The Glosten Associates, March 2, 2004

Dear John:

Thank you for including us in your survey of the tug and barge industry in connection with the study you described in your letter and meeting in our offices last week. We have been actively engaged in the tug and barge transportation business since the founding of our firm in 1958. Your interest in barges as a serious contributor to the transportation needs of the coastal community is encouraging. We are pleased to offer some assistance to your study base.

You asked some specific questions in the reference letter. The first relates to the issue of power and speed. This question has a myriad of answers depending on the particular route, cargo value and other economic issues. The enclosed technical paper which Steve Scalzo (currently President of Foss Maritime) and I authored some years ago, addresses the basic matter and will, I hope, give you some information to assess speed, power and tug/barge issues. More specific answers will depend on some of the factors noted above. We do know, however, that a towed barge compares best in economic models when speeds are modest, i.e., less than 12 knots.

The recent re-introduction of articulated tug/barge units has added a dimension of speed to the industry not previously available. This is because the linkages are being well accepted on the West Coast and are providing good service in the petroleum trade. The powering and resistance of those units approach ships of the same size.

You also asked about draft issues, and we noted that draft can be a serious constraint if a particular tug-barge unit must go to sea. Seakeeping and structural issues drive one to length/draft ratios that make very shallow draft operations uneconomic in exposed ocean waters. So, one would expect that coastwise vessels, whether ships or barges, would not have drafts less than 14 feet.

We discussed emissions issues and reiterate that the 2007 regulations will be met by the engine types that one would use in a typical tug.

The issue of ro-ro barge cargo not using the deadweight capacity of a vessel has been addressed by innovative cargo matching. One might consider either bulk cargoes below deck, or double decking with somewhat more dense cargo. Of course, if the cargo is valuable, then the operation can be economically viable. Examples are the interisland auto trade in Hawaii, and the Tote ships.

The question of economic competition of lower cost tugs and barges has always been at the heart of the ability of the industry to survive in face of competition from the railroads, trucks and other commercial ships. But, as we noted a principal reason for the attractiveness of tugs/barges is the manning advantage. That advantage is imbedded in the archaic issues of admeasurement and register tonnage. If one really wanted to make coastwise shipping fully competitive with land based alternates, then the issue of reduced manning on ships (at whatever size and speed particular cargoes need) must be addressed. We hope that Marad will be supportive of that move.

We hope the foregoing is of use to you. Good luck with your study. We look forward to seeing your report in due course.

Yours very truly,

THE GLOSTEN ASSOCIATES, INC.

Duane H. Laible, P.E.
Chairman

DHL:ld

Enclosure: Scalzo, S.T. and Laible, D.H. "Rational Selection of Tug Type and Power"
cc: Larry Johnson

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Rational Selection of Tug Type and Power

Steve T. Scalzo, Foss Maritime Company, Seattle, Washington USA
Duane H. Laible, The Glosten Associates, Inc., Seattle, Washington USA

SYNOPSIS: The requirements for towing or ship assist operations vary widely. The application of a tug of particular size, power and propulsion arrangement can be assisted by engineering analysis of the proposed operation. This paper describes, through several examples, how engineering analysis; coupled with sound seamanship and judgement can aid an experienced operator in selecting the proper equipment for a given assignment.

INTRODUCTION

Foss Maritime Company began providing marine transportation services in the Pacific Northwest Region of the United States in 1889. Next year, Foss will celebrate its centennial year of operation. During the past 100 years, Foss has developed a complete waterborne tug and barge transportation system that currently operates throughout Puget Sound, Alaska, Southern California and along the U.S. West Coast. Foss deploys approximately 65 tugs and 65 barges in order to perform a multitude of commodity movements, vessel related harbor services and international and coastwise/ocean towing. During the past twelve years, Foss has also invested more than U.S. $150,000,000 in vessel conversions and new construction to rebuild and modernize its fleet of marine equipment. As these tugs and barges have been added to Foss' fleet, the type of design, size of vessels and propulsion systems have been selected with consideration to both the demands of the marketplace and the multitude of towing requirements to ensure that the vessels perform with a reasonable balance of efficiency, speed and safety.

Background

The rational selection process of tugs and tows has evolved in our industry from subjective methods based on the vast experience of the towing fraternity, along with empirical data and rules of thumb. Foss Maritime, with its relatively large fleet and long history of operation in hostile marine environments, has amassed a wealth of information on the performance of its tugs in combination with a wide variety of ship handling, harbor services and ocean/coastwise tows.

In the past ten years, the tug and barge industry has been dramatically affected by:

1) Increased competitive pressures brought on by excess equipment in the marketplace,
2) Increased vessel operating expenses, especially the cost of fuel oils and lubricants, and
3) An increased awareness of the risks and associated insurance costs with large, unusual and/or valuable tows.

For this reason, much more emphasis has been placed on matching tug performance to all the various types of towage requirements. This had led to the need to supplement the traditional empirical tug selection approach with enhanced engineering and analysis. Consequently, sophisticated tug selection and trip planning tools have been developed by Foss with the assistance of its marine engineering and naval architecture consultant, The Glosten Associates, Inc.

The following sections describe in more detail the three primary elements that comprise a rational tug selection process for harbor service and ocean towing:

Tug Performance
Tow Resistance Characteristics
Climatic Considerations

It needs to be emphasized that these three elements are each considered on the basis of past experience and practical knowledge gained over many years of operation, and supplemented with "modern engineering methods," which are then substantiated by actual job performance. Information about the capabilities of particular tugs, estimates of tow resistances and informed estimates of expected environmental conditions enhance the ability to evaluate risk and develop reasonable safety margins. The objective of this approach is to improve tow performance by reducing the physical and business risk associated with towage.

TUG PERFORMANCE

Tug performance data together with tow resistance information provide the information needed to effectively evaluate the safety and economy of a particular towing operation. How much and what kind of performance information varies depending on the demands of the operation, degree of departure from routine tasks, and the economic risk and value of the operation. Two broad categories of general interest that will be presented here are data needed to evaluate ocean and coastwise tows, and ship assist in an open roadstead. As noted earlier, this information supplements the practical knowledge of experienced operators and cannot be properly used without the judgement of those operators.

Ocean and Coastwise Performance Factors

Tug performance, as related to towing efficiency and effectiveness, can be expressed in graphical form as towrope pull versus speed. Figure 1 shows such a plot for a twin-screw, fixed-pitch, open propeller geared-diesel driven tug. Net towrope pull is the most convenient measure of tow performance, since the resistance of a variety of tows can be compared directly and reasonable estimates of speed for a given tug and tow can be quickly established.

4300 HP CLASS TUG

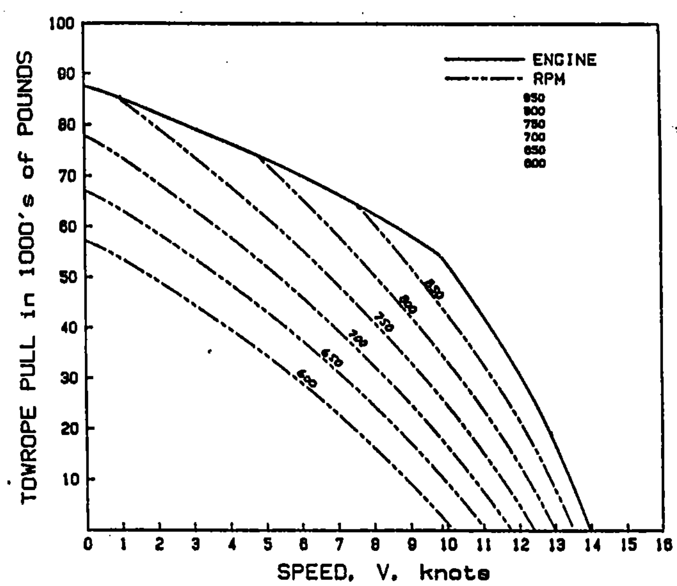


Figure 1

The first step in establishing a performance curve is to define all the tug-specific data that affect tug performance. The main factors taken into consideration in developing tug performance include:

* Vessel data: length, beam, draft, form coefficients, hull character and type (formed, chine, etc.)
* Main engine: size, rating
* Gear data: reduction ratio, allowances for auxiliary drives, etc.
* Propeller: size, type (fixed or controllable pitch)
* Shafting: arrangement, bosses, struts
* Presence of propeller nozzle

The information above is used to develop a "gross thrust" curve for the particular propeller using open-water performance data. By incorporating any applicable model test information, and full scale data of free running speed, bollard pull and other known information to establish hull-interaction factors, a "tug resistance" curve is developed which is subtracted from the "gross thrust" curve. This gives a "net towrope pull" for a particular condition of tug draft, fouling, engine state/condition and weather conditions. A family of curves can be developed to account for each of these factors. A more common approach is to assume average tug conditions in smooth water to establish the base. Then appropriate margins are applied to account for special conditions in a particular case. The important thing is to ensure that all operating variables have been considered whether in direct calculations or in allowances. Figure 1 is for a tug in normal operating conditions, and average draft with the hull condition that reflects Foss Maritime preventive maintenance practice. Foss Maritime has tug performance curves similar to Figure 1 for all major classes of its tugs and, where appropriate, vessel specific curves for different propellers within a particular class.

The data on towrope pull at governed RPM and maximum torque, which is the solid line, is the most important planning tool. The dashed lines in Figure 1 show the performance at reduced RPM so that judgements can be made about various strategies for carrying out an assignment. Fuel consumption data, using engine manufacturer's information and field measurements is also developed and plotted on the same figure (Figure 2) to assist in voyage planning and in developing sailing orders.

Figure 3 is a typical tug performance curve that shows the effect of choosing propellers designed for different purposes. The figure shows the variation in bollard pull, intermediate towing speed performance and free running speed for each of three propellers selected to optimize those particular capabilities. Also shown is a curve of a controllable pitch propeller that is equivalent to a variety of fixed pitch propellers.

The tug performance information shown in Figures 1 through 3 are for smooth water operating conditions. Similar curves can be developed for a variety of sea states if that level of refinement is warranted. Feedback from actual voyages and other similar experiences is used in establishing proper margins for a particular tow.

3000 HP CLASS TUG

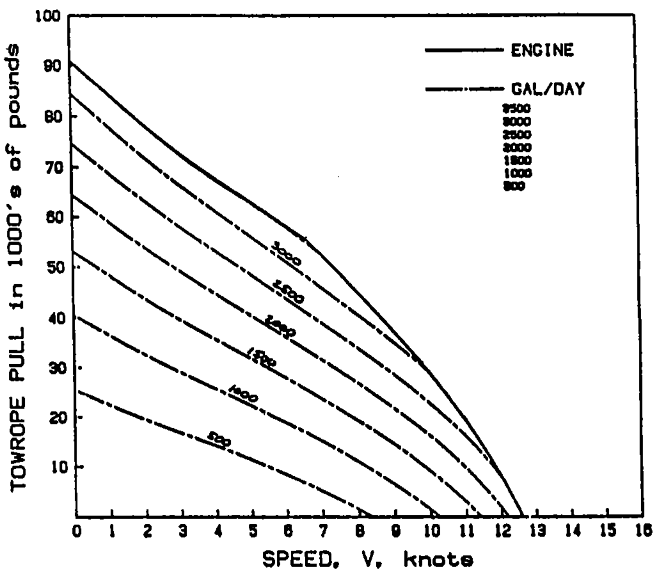


Figure 2

EXAMPLE 4200 BHP TUGS

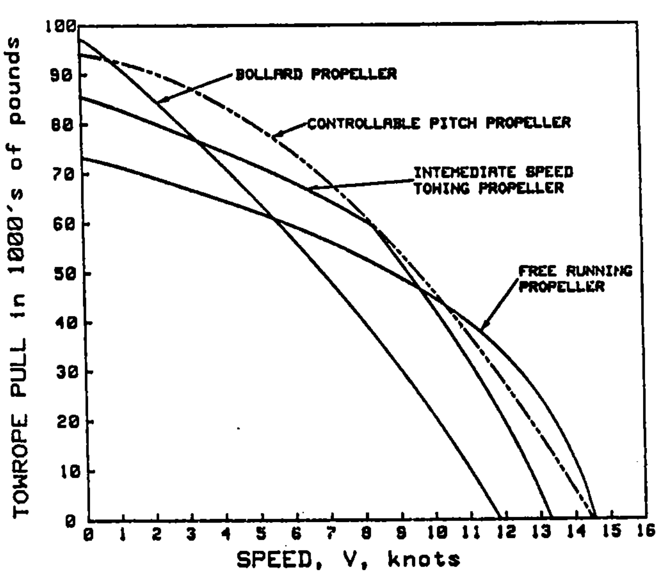


Figure 3

Harbor and Ship Assist Performance Factors

The selection of tug types for harbor and ship assist service has been the subject of numerous papers given at previous International Tug Conferences and technical forums throughout the world. Operators have chosen particular types for a variety of technical and operational reasons and the continuing acquisition of a wide variety of tugs, lends credence to a view that there is no one tug type that is perfect for all applications.

Foss Maritime has tugs of nearly all generic types in its fleet including twin screw open propeller tugs, twin screw with fixed propeller nozzles (with and without flanking rudders) twin-screw with steerable nozzles, tugs with controllable pitch propellers, and twin cycloidal propeller tractor tugs. Each tug type was selected not only to fulfill particular assignments, but also to meet broad fleet requirements and ensure equipment compatibility for ease of maintenance and training, and to ensure sufficient versatility to meet the wide spectrum of demands of a full service towing company.

Nonetheless, quite specialized craft have been added to the fleet in response to customer and service requirements. The addition of the tractor tugs was undertaken through the evaluation of numerous tug performance criteria such as zero speed thrust (bollard pull) both ahead and astern, stopping power, and lateral thrust. Other factors such as maneuverability and responsiveness, damage resistance, mechanical reliability and maintainability, simplicity of control and ease of operator training and, of course, economic consideration, have been evaluated in the selection of harbor and ship assist tugs.

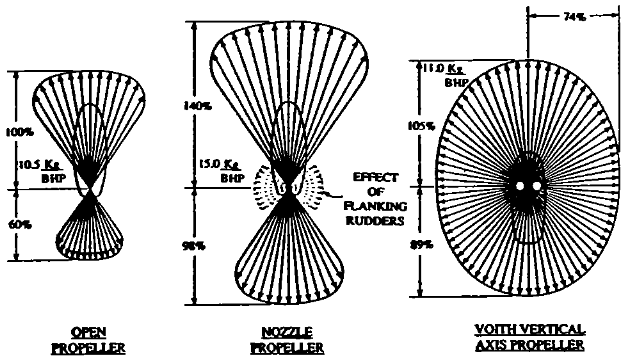
Establishment of tug performance measures for harbor and ship assist tugs is complicated by the fact that specific ports and harbors have widely varying geographic, climatic and operational features that influence the relative importance of the various tug characteristics. References 1 and 2 are examples of valid assessment procedures for both specific and general port characteristics. The principal elements of tug performance noted earlier can be calculated and then consideration of the geography of the port, environmental conditions, ship size and other special factors can be used to establish the selection criteria.

Zero speed thrust or bollard pull varies depending on what type of propellers are used and where they are located in the tug. Reference 3 has been credited with introducing the concept of the thrust envelope and Figure 4 shows the zero speed performance characteristics of three types of tugs. Similar envelopes can be developed for any tug.

Additionally, the ability of tugs to produce thrust at speed must be assessed. In principle, evaluation of the ability to produce thrust either astern or ahead while moving in either of these directions must be made. The usual situation encountered by all vessels when moving ahead and providing thrust in the direction of motion is known as "first quadrant" or quadrant I operation.

As speed is reduced one approaches the bollard pull condition. As speed is reduced still further it becomes negative and the towing vessel is itself being towed astern (motion and thrust reckoned from the frame of reference of the towing vessel) while providing thrust ahead. This mode of operation has been termed a second quadrant or quadrant II operation. The thrust plane diagram from which the quadrant definitions derive is shown in Figure 5. The ahead bollard pull lies on the positive vertical axis at zero speed and the astern bollard pull lies on the negative vertical axis.

THRUST ENVELOPES FOR TUG PROPULSION SYSTEMS



DIAGRAMS DEPICT PERFORMANCE
IN BOLLARD (V=0 KTS) CONDITION

Figure 4

THRUST - SPEED QUADRANT DEFINITION DIAGRAM

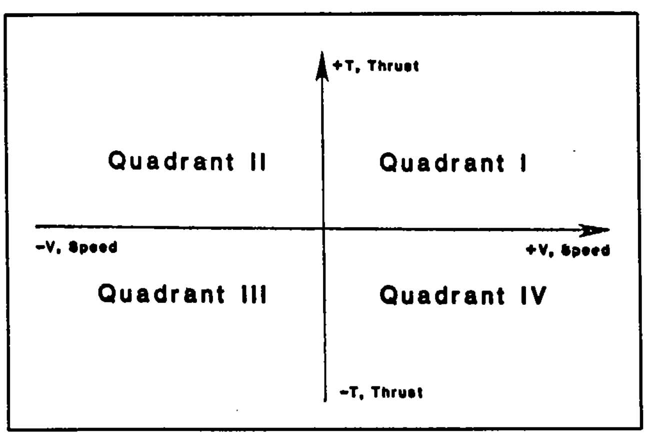
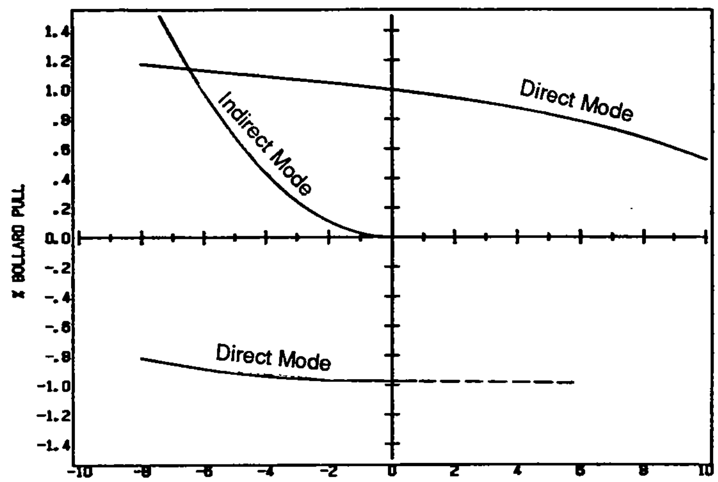


Figure 5

Depending on the location of the propulsion units in the tug, and depending on its line handling outfit, a tug may perform braking in a quadrant II mode, as with a tractor or in quadrant IV, as with a stern driven vessel working on a headline. This is the classic retard or braking operation so critical to the safety of large vessels negotiating restricted waterways.

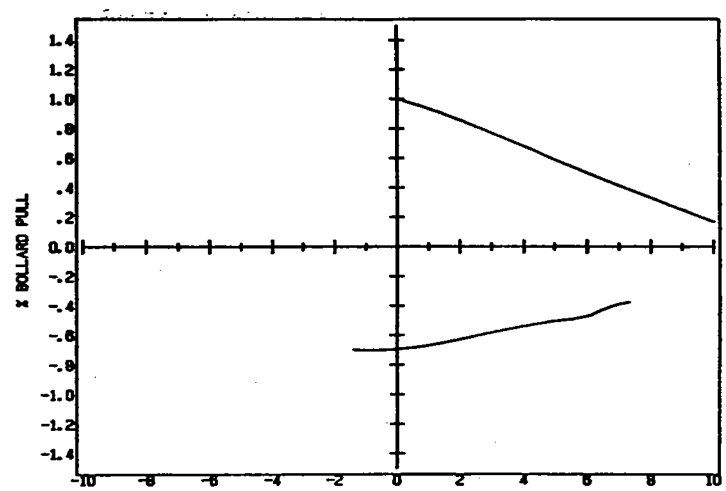
CYCLOIDAL PROPELLER TRACTOR TUG FOUR QUADRANT PERFORMANCE



SPEED, V, knots

Figure 6

NOZZLE TUG FOUR QUADRANT PERFORMANCE



SPEED, V, knots

Figure 7

Non-dimensionalized curves giving the performance of tugs in all operating quadrants can be developed using data such as given in Reference 4 for varying levels of power and size of tugs. It must be noted that actual operating experience must be taken into account to avoid selection of tugs which cannot perform certain maneuvers beyond minimal speed. Figures 6 and 7 show the performance of a cycloidal propeller tractor tug and a stern driven fixed nozzle tug and the quadrants in which these particular tugs are effective [5].

We have now considered fore and aft thrust at zero speed and while underway in either direction. Another important issue is the production of lateral thrust while the tug is underway or operating in a current. This capability is of principal concern when operating in restricted channels with beam wind, and when assisting vessels at berths subject to strong tidal currents. The zero speed thrust envelopes are of some assistance in evaluating this capability, but a more complete model must be developed to fully establish this tug capability.

The analysis of lateral force while operating in a current must take into account propeller arrangement and location, size and capability of rudders and steering system, and underwater hull configuration including size and location of fixed appendages. A mathematical model can be constructed to evaluate the x-y (ahead and lateral) components of thrust as a function of free stream (current) velocity and angle between tug and assisted vessel. The principal objective is to maximize lateral thrust without production of axial forces, particularly if assisting a ship to a berth in a current. Figures 8 and 9 show the lateral thrust of a twin screw open propeller tug and a fixed nozzle tug of somewaht smaller size and show the relative advantage of the open propeller tug for this maneuver.

LATERAL FORCE VS SPEED

96 FT LWL - 2200 BHP TWIN SCREW TUG

WITH 4 BLADE PROP, 92 IN DIA, 70 IN PITCH, OPEN WHEEL

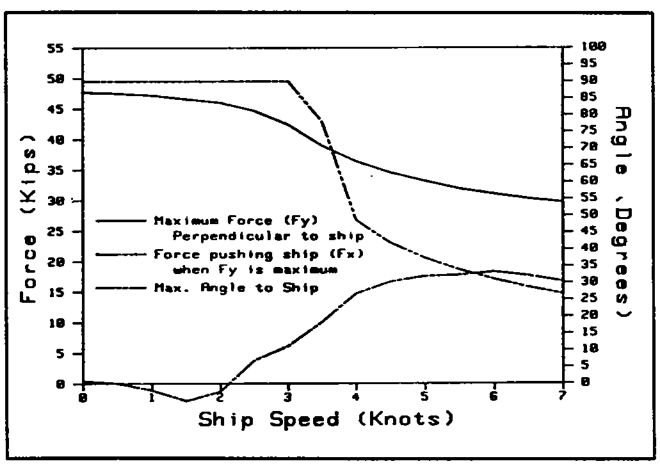


Figure 8

LATERAL FORCE VS SPEED

76 FT LWL - 1700 BHP TWIN SCREW TUG

WITH 4 BLADE PROP, 76 IN DIA, 76 IN PITCH, 19A NOZZLES

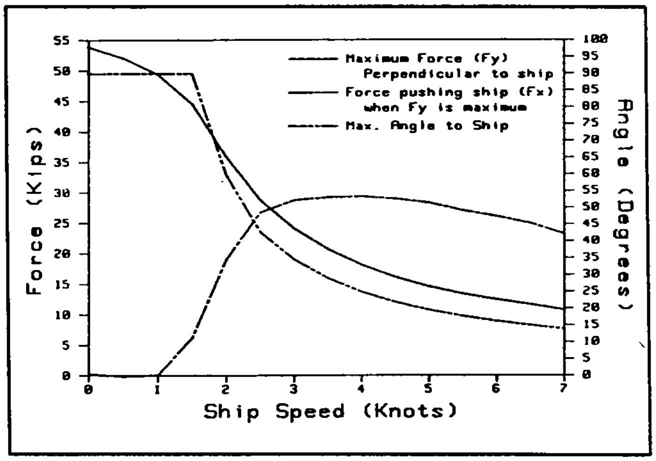


Figure 9

CYCLOIDAL PROPELLER TRACTOR TUG

SECOND QUADRANT PERFORMANCE

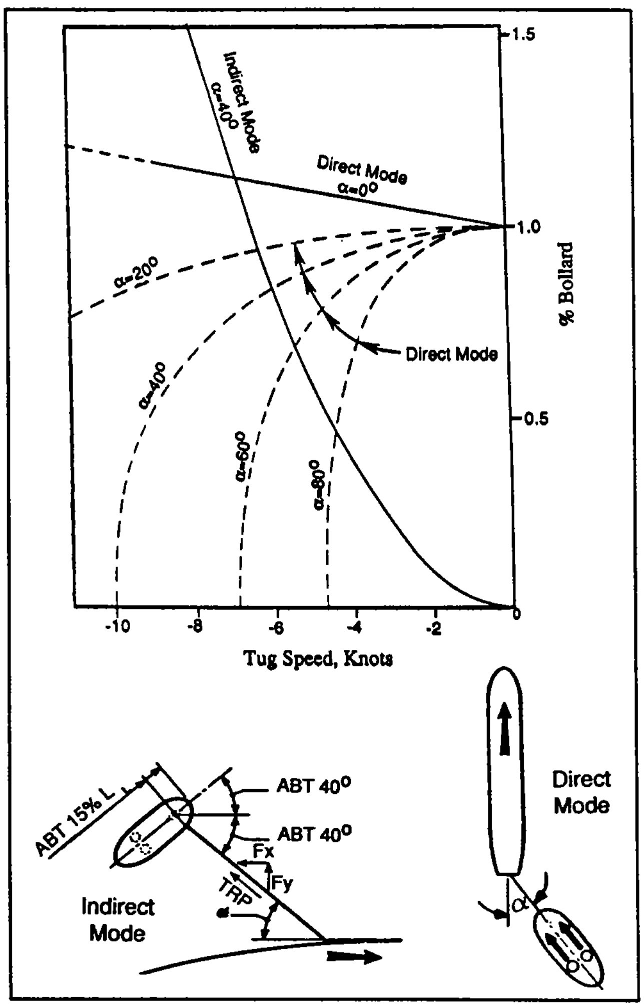


Figure 10

Tugs with omni-directional propulsion such as cycloidal propellers or rotatable nozzle thrusters generally have substantially greater ability in this maneuver than fixed systems. Figure 10 shows the general character of cycloidal propeller tractor tug capability.

Evaluation of the lateral force capability is further complicated by the question of whether the *North American* (tug made up fast to the assisted vessel) or *European* (tug on a line) ship-handling techniques are used. This is often a matter of tradition, pilot preference, port geography and berth arrangements. Nonetheless, these factors must be evaluated in a rational selection process.

Tow Resistance Characteristics

Coastwise and ocean towing operations require consideration of the two elements previously noted, i.e. tug capabilities and towed object characteristics. This section discusses the second half of the tow prediction problem which is the resistance of the towed object. The net towrope pull curve of the tug gives the available pull as a function of tug speed. Similarly, the resistance to be overcome when towing a specific object under particular weather conditions can be plotted over the same speed range. The principal elements in predicting the resistance of an object include the following.

* Bare hull characteristics
* Appendages such as rudder, skegs, propellers
* Above water characteristics affected by wind
* Form characteristics that affect resistance as a function of sea states (e.g., bluff vs. ship-shaped bow barges)

We have accumulated data on a wide variety of towed objects including barges, oil rigs, caissons, ships etc., from which towing resistance curves can be developed. Again all factors such as towline resistance, hull condition and other such elements must be specifically included in the resistance curve or the allowances so that consistent answers are established.

Examples of typical curves used in predicting overall tow performance, Figures 11 through 14, are discussed below.

Barges:

Figure 11 depicts the resistance of a *Foss 286* Class barge at a given draft with a windage area that approximates a 2-high stack of containers. The curve is based on model test data and includes some of the fixed elements such as skegs, average towline length and self-windage. However, special allowance for particular weather conditions is done separately. Similar curves have been developed for other load conditions and operating drafts for both single and tandem tows.

Dead Ships:

Resistance curves for dead ships are generally developed using either model test, standard series data, or regression for bare hull resistance (for example, Holtrop & Mennen Reference [6]). Appendage allowances, including locked propellers, if present, towline resistance, and fouling factors can then be added to produce a total smooth water resistance curve. Resistance due to wind is then usually added as a separate factor. Added resistance due to waves is usually accounted for in a speed margin but in special circumstances calculated resistance using the method of values are added to the baseline curves.

Figure 12 shows a curve for a light SL-7 dead ship tow. The steepness of the resistance curve without any head wind clearly shows that the dominant resistance effect is that of the locked propeller (twin screw). The curves of resistance at various wind speeds are useful in assessing voyage risks.

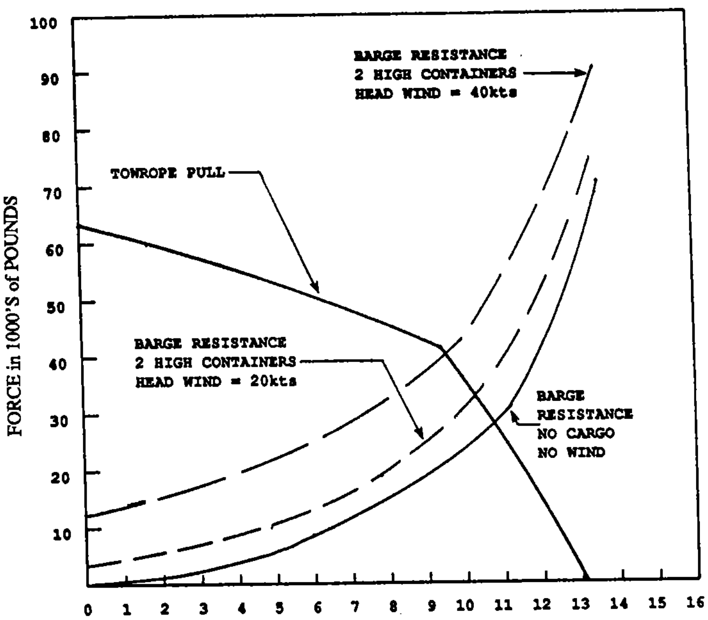
Unique Tows:

(a) Caisson:
Figure 13 is the resistance curve for a very simple caisson or pier for which the resistance characteristics are determined by the form drag of the object. Windage is not a principal factor, nor is wave making, since the tow speeds are slow. The principal concern would be with encountering unexpected currents.

(b) Drydock:
Figure 14 shows the resistance curve for a sectional drydock unit. The design of the dock is such that the units must be towed with the towing bridle attached to one wingwall which results in maximizing the windage area. The behavior of this tow is dominated by the wind drag, so the effects of waves are relatively small. The towing performance of two different tugs was estimated and in both cases actual performance correlated very well with the prediction.

Using a tug performance curve, and a tow resistance curve for a particular object, the predicted speed for that combination of vessels can easily be established. Then careful consideration of other factors not specifically included in the tow curves is applied to give a predicted average speed that can be made while, for example, consuming a given amount of fuel. Judgements regarding extreme events can also be made using this information. Various margins are added to account for weather or the techniques described in the climatology section are applied to provide more refined predictions and/or to increase confidence in the safety margins that have been allowed.

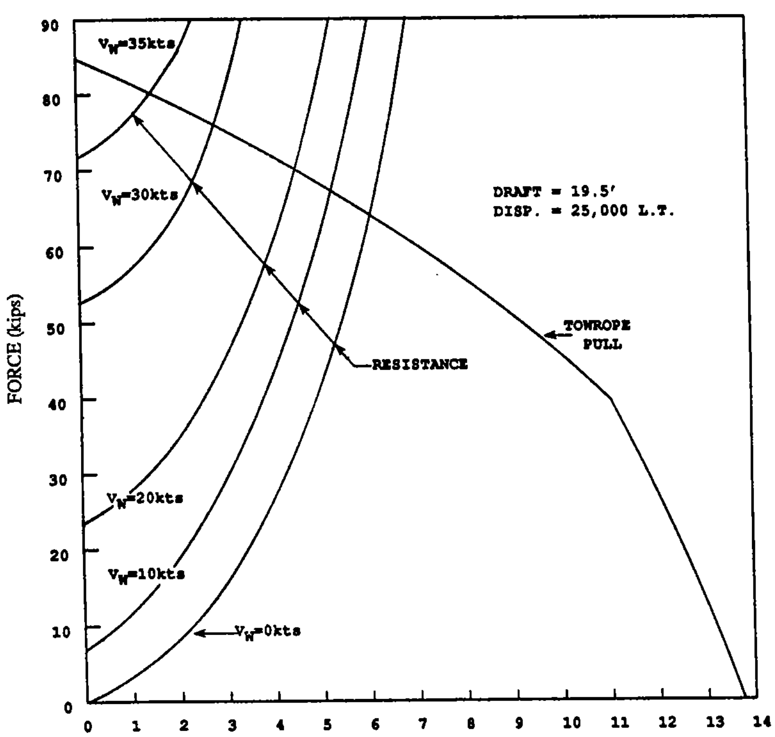
M/V SIDNEY FOSS
TOWING BARGE *FOSS 286*
AT 8 FOOT DRAFT



SPEED, V, knots

Figure 11

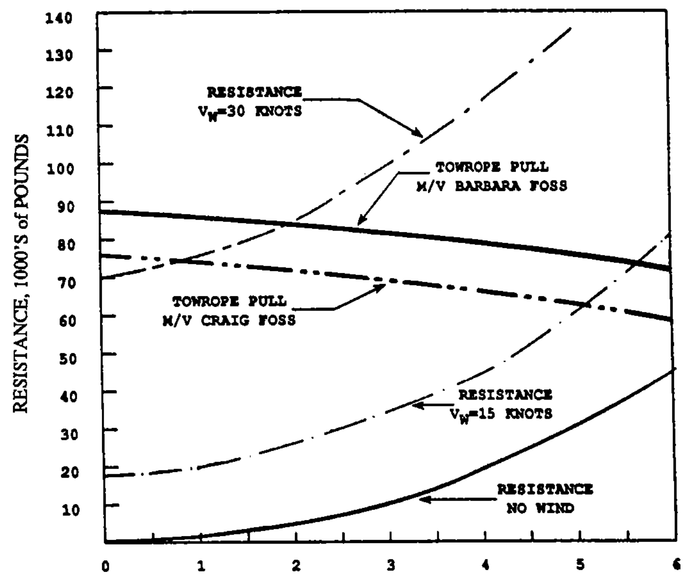
M/V BARBARA FOSS TOWING
SL-7 CONTAINERSHIP IN LIGHT CONDITION



SPEED, V, knots

Figure 12

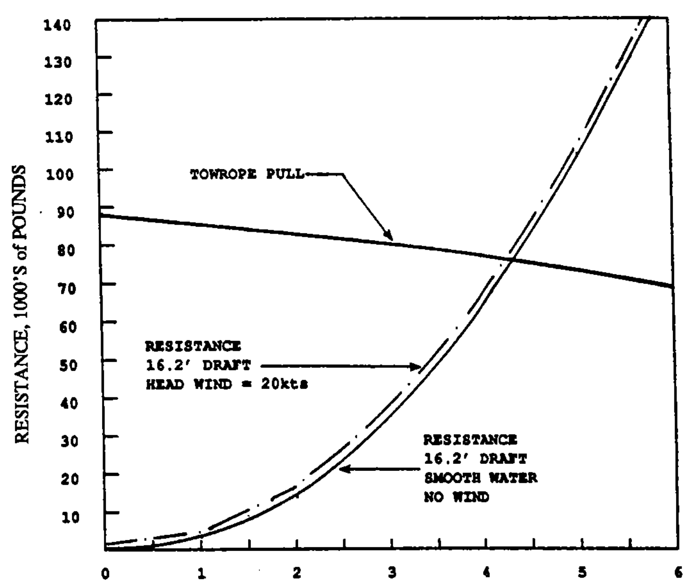
M/V BARBARA FOSS
TOWING VALDEZ CONTAINER DOCK



SPEED, V, knots

Figure 13

M/V BARBARA FOSS OR *M/V CRAIG FOSS*
TOWING DRYDOCK SECTIONS



SPEED, V, knots

Figure 14

HARBOR AND SHIP ASSIST ANALYSIS

An example of the application of harbor and ship assist analysis techniques is the evaluation of the comparative performance of cycloidal propeller tractor tugs and conventional twin screw open propeller tugs during the escort and assist of 125,000 DWT tankers in Northern Puget Sound, Washington. Federal and State of Washington regulations prescribe the use of tugs in the operation of tankers arriving at refineries in these waters.

The route and area of operation for the North Puget Sound tanker escort assist operation is shown in Figure 15. Tankers arriving via the Strait of Juan de Fuca enter the restricted operating area off Port Angeles. The majority of vessels go northeast through Rosario Strait and turn into Guemes Channel to berth at refineries off Marsh Point near Anacortes or continue northward into Strait of Georgia to refineries near Cherry Point. Vessels serving Seattle and Tacoma turn southward through Admiralty Inlet and pass into Puget Sound.

PUGET SOUND TANKER ESCORT ROUTES

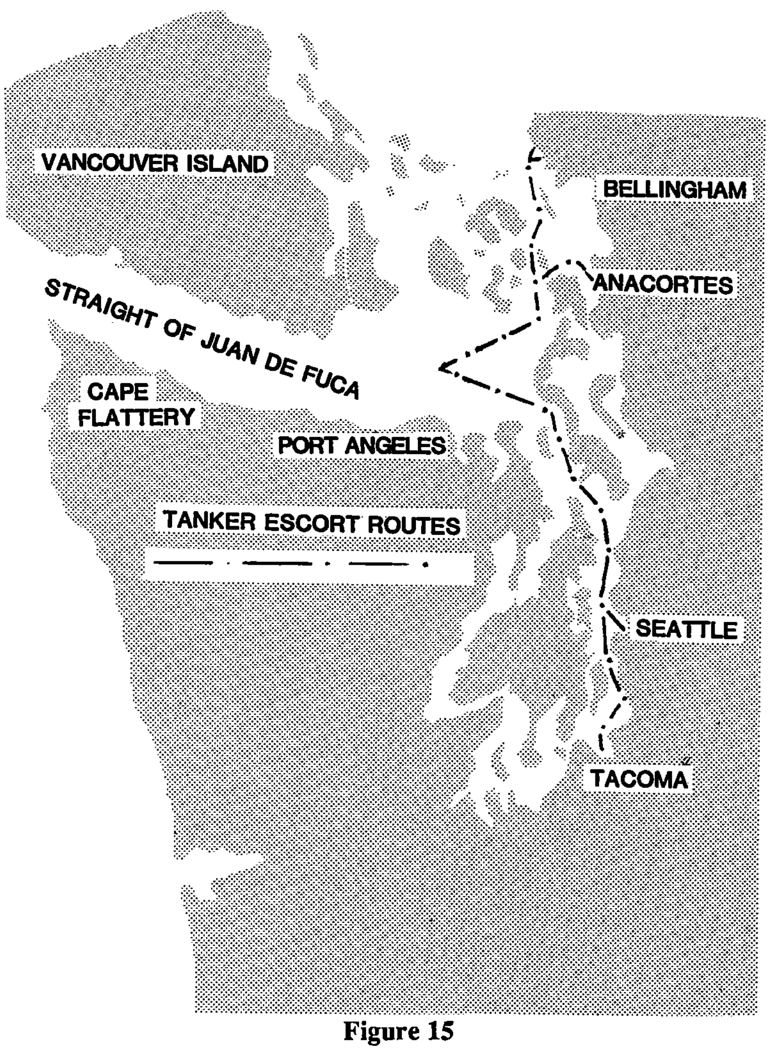


Figure 15

Since 1975, when Washington state law first required tug escort for all tankers over 40,000 DWT, a variety of tug types have served this market. In subsequent years, a substantial amount of data was collected regarding tanker/tug interaction and full scale trials were conducted to document and collect data [References 7,8,9]. Additionally, surveys of tanker assist operations throughout the world and consultation with many successful operators led to the conclusion that specialized tugs were suited to the operating demands of this service.

The following discussion is based on analysis of a typical 125,000 DWT tanker and twin screw tug, characteristics of which are given in Reference 7. This is but one element of the question regarding tug selection for this service.

Three principal areas were examined in the comparison between tug types, namely:

* Escort Service - Retardation, i.e. Stopping Ability
* Escort Service - Control and Emergency Steering
* Docking Assist Operation

Escort Service - Retardation

To examine the first question which bears on the ability of a tug or tugs to provide effective stopping force in the event a tanker were to lose power during transit it was necessary to model the stopping power of a tug over a range of speed. Figure 16 shows in graphical form the sequence of events and the stopping distance from an assumed initial speed of 12 knots. The computer simulation on which this is based takes into account the practical elements of tug operation such as speeds at which cycloidal propelled and conventional stern driven tugs can make up lines, engage engines and effect retardation forces at varying speeds.

The comparisons show that a single cycloidal propelled tractor can stop a 125,000 DWT tanker more quickly than the conventional tug. The even more dramatic difference (41% reduction in time) however, is the stopping ability of two tractors as compared to the single conventional tug. The point should be made that using two tractors is not only possible, but a common operation in the world's ports, while tanker trials have shown that attempting to use two conventional tugs at the stern is risky due to possible damage.

The ability of the tractor tug to stop the tanker comes principally from the ability to begin thrusting astern, even at relatively high forward speeds, using the controllable pitch features of the propeller. The conventional tug cannot apply effective retarding forces until the tanker slows enough to avoid engine stall. Figure 17 shows that at speeds in excess of 8 knots the only retarding force from a conventional tug is the drag of its hull and locked propellers. At lower speeds the tug still risks engine stall.

STOPPING DISTANCE OF 120,000 DWT TANKER AFTER POWER FAILURE WITH VARIOUS TUGS ASSISTING

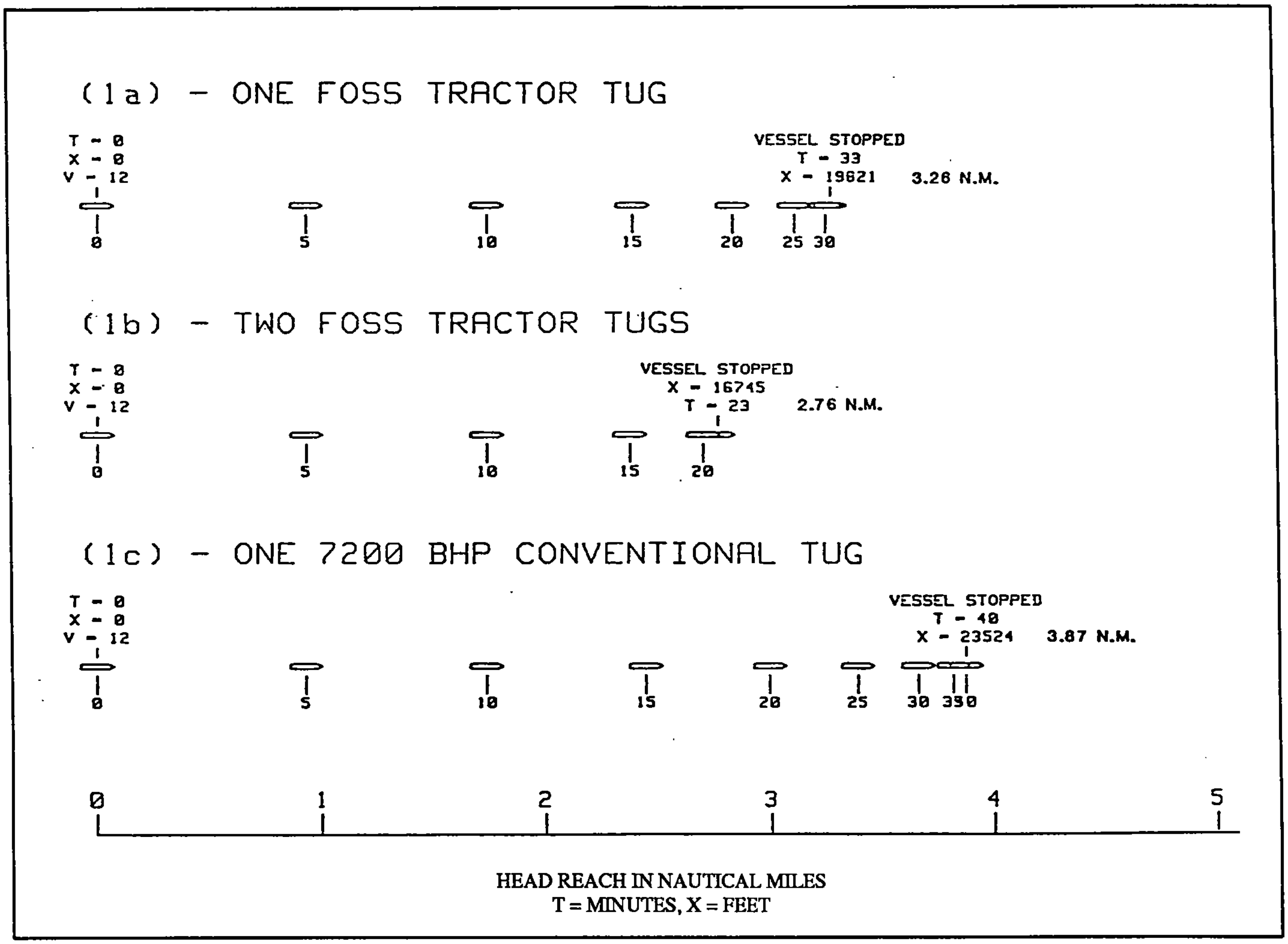


Figure 16

TUG RETARDING FORCE CAPABILITY VS SPEED

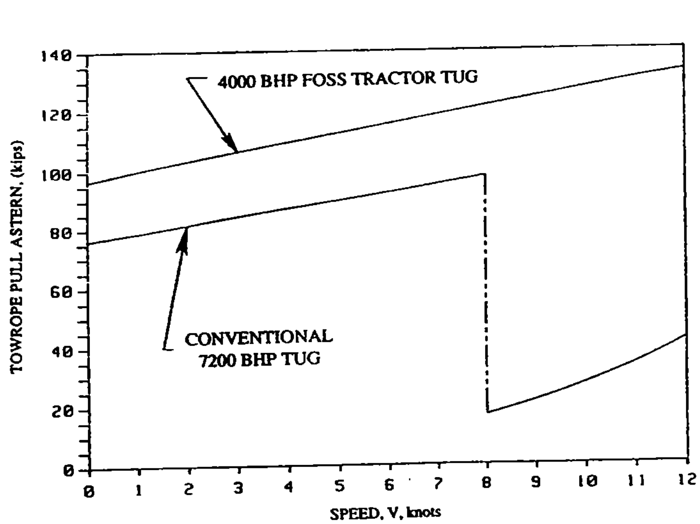


Figure 17

Escort Service - Control and Emergency Steering

Another serious accident scenario is steering failure. A whole range of possible casualties can be hypothesized, but in general if the tanker suffers a casualty, the most useful assistance would be in the form of a steering force to straighten out the vessel and guide it along its safe route. In an open roadstead, it might also be desirable to accelerate the turn and thus stop the tanker with a minimum of headreach.

To illustrate the capability of the tractor tug the following table shows the estimate of a 125,000 DWT tanker rudder steering force and the effective side force produced by one, or two cycloidal propelled tractor tugs, or a conventional tug of 7200 BHP.

TABLE I
TANKER STEERING AND TUG LATERAL FORMS

Speed (knots)	Tanker Rudder Force	One Tractor Tug	Two Tractor Tugs	One Conventional Tug
	(All forces in thousands of pounds)			
10	240.	174.	262.	0.
8	160.	112.	167.	0.
6	90.	76.	151.	1.
4	40.	87.	173.	11.
2	10.	94.	187.	79.
0	0.	96.	192.	112.

Figure 18 shows this information in graphical form. If the tanker curve is seen as the "required" force to perform a hard-over maneuver, then it can be seen that two tractor tugs can do so at all speeds up to 10 knots. One tractor tug can do so at nearly 6 knots, and the conventional tug is quite ineffective beyond speeds of 3-1/2 knots.

Note that the tractor tug can produce substantial steering forces at relatively high speed, because it is specifically designed for this particular capability in the indirect mode of operation.

Docking Assist Operation

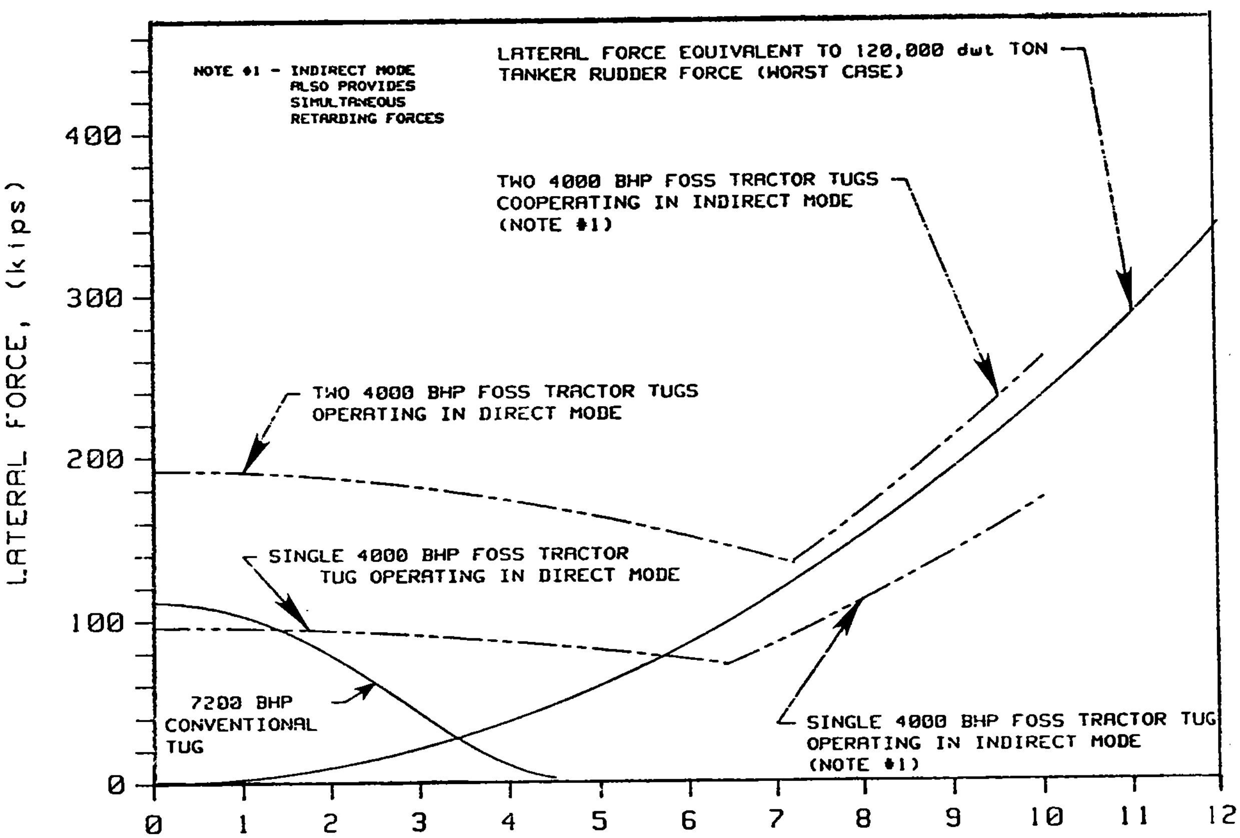
At relatively high speeds (4 knots to 10 knots) the cycloidal tractor tugs can produce significant lateral forces by operating in the indirect mode at the end of a line. Conventional tugs can simply not perform equivalent maneuvers.

At low speeds the differences between a tractor tug and conventional tug are still substantial because of the greater ability of the tractor tug to develop thrust in any direction. A conventional tug is not as able to produce the thrust needed to counter the effects of current on the exposed underwater body as the tug attempts to orient itself at right angles to the tanker. Consequently, the effective lateral force falls off because of speed of the assisted tanker or the current.

If the conventional tug puts up a line from its bow to the assisted tanker, then side force caused by current or speed of the tanker can be overcome by running the tug propellers in opposite directions. The net useful force on the assisted tanker is, however, quite small.

The tractor tug can, however, direct the thrust in any direction so that it can find an angle relative to the tanker centerline that optimizes the lateral force. Reference to Figure 18 shows this at low speed wherein the tractor has much higher lateral force at all but bollard conditions.

LATERAL FORCES VS SPEED



SPEED, V, (knots)

Figure 18

It must be acknowledged that purpose built tugs of any type should be superior to multi-purpose tugs in that particular situation for which the specialty tugs were constructed. Therefore, the economic consideration that an operator faces may lead him to select one tug over another because of economic compromises. The example discussed herein shows the advantages of a specially constructed tug over a multi-purpose tug, but even if the conventional tug were fitted out with optimum gear box, propeller and deck outfit, it seems likely that the inherent advantage of a tractor tug to respond to a tanker casualty at relatively high speeds would still prevail.

Nevertheless, the literature describes many instances when operators have chosen a variety of tugs to serve a particular port, and this is exactly what Foss Maritime has done. The extreme conditions of North Puget Sound tanker escort/assist seem well met by cycloidal propelled tractor tugs.

CLIMATIC CONSIDERATIONS

The marine environment, through which a planned ocean tow must proceed, varies both in location and time. It is commonly recognized that the conditions anticipated for a voyage across the Gulf of Alaska in December are much more severe than those for an August voyage, (an example of variation in time represented by different operating seasons). However, there can be good December voyages and bad August voyages in the Gulf of Alaska. Likewise, a voyage across the Caribbean Sea in January is expected to be much more benign than a January voyage across the North Sea (an example of variation in location represented by different operating domains).

The characterization of these variations is conveniently accomplished using probabilistic methods. Two recent technical papers which present the general theory of probabilistic voyage analysis and present examples of the application of the theory are References 10 and 11.

Reference 10, by Bruce L. Hutchison, is the first comprehensive statement of a general theory for the probabilistic analysis of voyages through spatially and temporally variable climatologies including the effects of seamanship. One of the examples considered concerns the complete pre-voyage analysis for an historically significant Foss Maritime tow of the barge *Foss 245* from Virginia to Oregon with a cargo consisting of a radioactively contaminated nuclear power plant steam generator. This analysis was prepared as part of the permitting process requirements for probabilistic risk analysis and was judged to meet those requirements by the U.S. Department of Energy, and U.S. Department of Transportation.

The *Foss 245* was instrumented with a real-time motion monitoring system which provided real-time advisory information to the master of tug *Agnes Foss* and recorded archival data for post-voyage analysis. After completion of this voyage the Glosten Associates analyzed the archival record. The post-voyage analysis has been the subject of a separate technical paper by Hutchison [Reference 12]. Included in the post-voyage analysis was a careful comparison of measured and predicted response which verified the accuracy and usefulness of the prediction methods.

The second and more recent reference concerns a careful comparison of predicted and recorded performance of The British Fisheries Protection vessel *FPV Sulisker* over a 15 day operating period off the north of Scotland. The probabilistic voyage analysis methods are those of Hutchison. The study concludes that very good correlation is possible between predicted and actual performance in spatially and temporally variable marine climatology, including the effects of seamanship.

The environmental state variables of interest to ocean towing include the following:

* Wind: speed, direction, duration
* Waves: significant wave height, mean period, direction, and spreading
* Current: speed, direction
* Hurricanes, Typhoons, Tropical Storms: season(s), tracklines, frequency, intensity
* Ice: cover
* Superstructure Icing
* Visibility

All of these variables can be represented by probability distributions. Where appropriate it is usually possible to obtain joint or conditional probability distributions as well.

The following typical sources of climatological data by spatial domain and season have been used in the past:

1. The U.S. Naval Weather Service Command <u>Summary of Synoptic Meteorlogical Observations</u>, commonly referred to as SSMO's. These are archived at the National Climatic Center in Asheville, South Carolina and available through The National Technical Information Service (NTIS). The source of the data is participating vessel observations. Areas covered include most of the world's coastal regions. Presentation is both by month and annual summary.

2. The <u>U.S. Navy Marine Climatic Atlas of the World</u>. These cover all the world's oceans and present synoptic observations by participating vessels in myriad local domains scattered throughout the oceans. Presentation is both by month and annual summaries.

3. Ocean Wave Statistics by N. Hogben and F.E. Lumb (1967) available from Her Majesty's Stationery Office, London. These present summarized observations of height, period and direction for local domains scattered throughout the world's oceans, principally along the major commercial shipping routes of what was the British Empire. Summaries are presented both annually and by month.

4. Standardized Wind and Wave Environments for North Pacific Ocean Areas, David W. Taylor Naval Ship Research and Development Center. This report is a source document for specifying wind and wave conditions for the North Pacific Ocean. Data are derived from the U.S. Navy's Spectral Ocean Wave Model (SOWM) hindcast wind and wave climatology. The report provides seasonal and geographic distributions of wind and wave parameters.

5. Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska, presentation is by month and spatial domain.

6. Arctic Ice Atlas by Arctic Environmental Information and Data Center (AEIDC), data by month and location.

7. Historical Extreme Winds for the United States: Atlantic and Gulf of Mexico Coastlines, Changery, M.J. (NOAA), Asheville, North Carolina, May 1982, 157 p.

8. Tropical Cyclones of the North Atlantic Ocean, 1871 - 1977, Neumann, Charles J., et al, National Climatic Center, Asheville, North Carolina, June 1978.

9. Guide to Standard Weather Summaries and Climatic Services, "Revised Uniform Summary of Surface Weather Observations," (RUSSWO), Naval Weather Service Environmental Detachment, Asheville, North Carolina, January 1973.

Numerous other marine climatic data sources are listed in the U.S. Department of Commerce, Selective Guide to Climatic Data Sources, Key to Meteorlogical Records Documentation No. 4.11, by Warren L. Hatch, which was published by NOAA in 1983. These climatic databases can be supplemented with information from the Mariners Weather Log (a NOAA quarterly journal) and with information derived from the numerous technical papers which have focused on detailed climatology in limited domains.

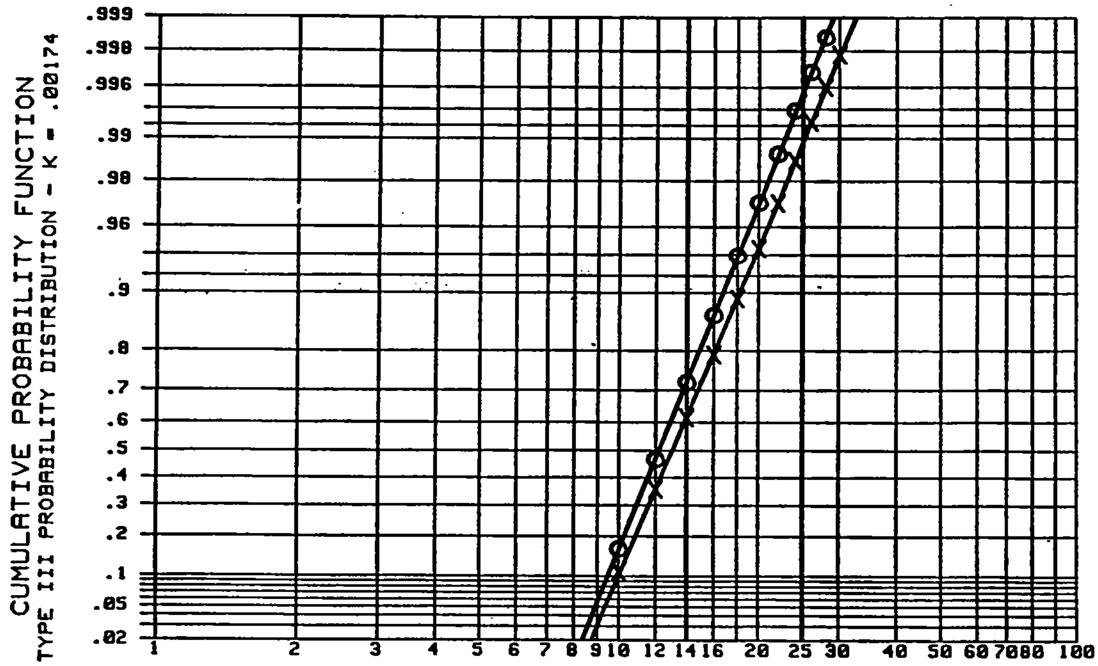
A sophisticated analysis of the climatological risks associated with an ocean tow may be simple, or complex depending on the nature of the tow and the corresponding concerns. An analysis might consist simply of extrapolating the extreme value for key climatological state variables (e.g. 100 year return values for wind speed and wave height), and examining tow performance (i.e. speed) for the proposed tug. A complex analysis might consist of Monte Carlo simulation of a large number of similar voyages (e.g. 10,000 voyages) through the same spatially and temporally distributed climatological environment.

Several approaches may be used to implement the analysis techniques of Reference 10. One example is a study that compared the sea state exposures during the summer shipping season routes from the U.S. West Coast and alternatively the Far East, to Alaska. The study evaluated the climatology on these two routes and formulated comparisons in terms of voyage risk probabilities for encountering different sea states. Figures 19 and 20 from that study show a direct comparison of the probability distribution of wave heights encountered for the two sea routes. These statistics were developed using a transit speed of 8 knots and an independence period of 12 hours. Significant wave heights at any statistical level can be read directly from the regression curves and comparisons between the two routes can be easily accomplished. By reading the horizontal scale at any given statistical level, the significant wave heights for the two routes can be determined. Likewise, by reading the vertical scale, the probability of non-exceedance for any given sea state parameter for the two routes can be compared. For the sea state standard of 14 feet the probability of exceedance for the U.S. West Coast route to Alaska is 27.52% (1.000-.7248) in July. At the same statistical level the significant wave height standard for the Far East to Alaska route would be 15.07 feet. For the 25 foot significant wave height the July probability of exceedance is 0.44% (1.000-.9956) for the U.S. West Coast route. The comparable wave height at the same statistical level is 27.8 feet for the Far East route.

A consequence of this analysis yielded two approaches for the selection of sea state parameters for use as design criteria. The first approach requires the choice of an acceptable risk level and as a consequence incurring the direct cost required to design for a higher significant wave height for Far East to Alaska voyages. For example if the risk level associated with the 14 foot and 25 foot U.S. West Coast Standard criteria for August were selected, then significant waves heights of 14.7 feet and 28.2 feet would have to be used as design criteria for the Far East route.

The second alternative is to design to one sea state standard and incur the indirect risk factored cost due to the difference in risk levels for the two routes. Design in this instance refers not only to the towing operation, but also the selection of appropriate sea fastenings and structural capabilities of the cargo.

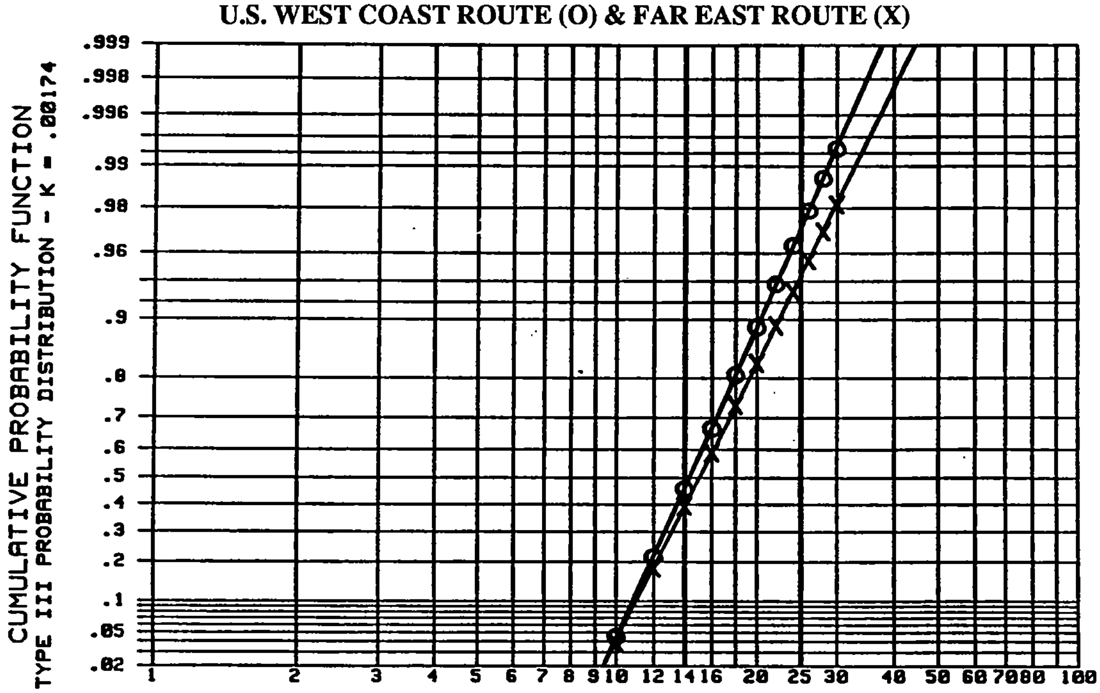
PROBABILITY DISTRIBUTION OF WAVE HEIGHTS ENCOUNTERED - JULY
U.S. WEST COAST ROUTE (O) & FAR EAST ROUTE (X)



SIGNIFICANT WAVE HEIGHT (Feet)
PROBABILITY OF ENCOUNTER: Hs => 14 Ft, WEST COAST: 0.2752 FAR EAST: 0.3805
PROBABILITY OF ENCOUNTER: Hs => 25 Ft, WEST COAST: 0.0044 FAR EAST: 0.0106
Towing Speed: 8 knots - Independence Period: 12 hours

Figure 19

PROBABILITY DISTRIBUTION OF WAVE HEIGHTS ENCOUNTERED - AUGUST
U.S. WEST COAST ROUTE (O) & FAR EAST ROUTE (X)



SIGNIFICANT WAVE HEIGHT (Feet)
PROBABILITY OF ENCOUNTER: Hs => 14 Ft, WEST COAST: 0.5374 FAR EAST: 0.6101
PROBABILITY OF ENCOUNTER: Hs => 25 Ft, WEST COAST: 0.0274 FAR EAST: 0.0551
Towing Speed: 8 knots - Independence Period: 12 hours

Figure 20

Another application of probabilistic methods is shown by an example wherein Foss Maritime Company had several barge loads of drill platform components awaiting departure from Seattle for shipment to Cook Inlet, Alaska in late Fall. The scheduled shipping dates were later than had originally been anticipated, so an evaluation of the economic tradeoff of departure time from Seattle was made to enable an evaluation of operating cost economics which were tug/barge costs versus on-site construction costs.

The problem arose because the equipment was scheduled for installation by crane on a platform being constructed on Cook Inlet. Since there was no safe, convenient on-site storage for the barges, the platform components could not easily by shipped to the site, and the ocean tugs discharged. The optimal condition was to have the platform components arrive just in time to be installed.

The principal economic elements of the problem were the on line costs for the tugs and barges, the daily rate of the crane barge at the site and the value of the cargo. The first item would result in extra cost if the cargo arrived early, the second would generate a cost if the cargo arrived late and the third factor would enter the equation as a potential cost arising from damage or loss in transit. The risk of the latter increased as the season advanced, and the likelihood of encountering even more severe storms increased.

The ideal trip consisted of approximately four days voyage in the Inside Passage from Seattle to Cape Spencer, Alaska, a two days crossing of the Gulf of Alaska and one day into Cook Inlet. However, the uncertainties of the project included the scheduled lift date at the platform which was subject to weather and progress on other construction elements, and the fact that the Gulf of Alaska experiences a storm of gale intensity on a nearly daily basis.

A Monte Carlo simulation was developed which considered the expense perturbations noted above and the following probabilistic elements:

(a) The time between storms in the Gulf of Alaska was modeled with an exponential probability function such that the median time between storms was 24 hours.

(b) The waiting time at Cape Spencer was equated with the time between storms obtained from a sample of the exponential distribution described in (a).

(c) When the simulated tow proceeds across the Gulf, if the time between storms is less than two days, then a storm is encountered.

(d) If a storm is encountered, then there is a one-in-a-hundred (probability 0.01) chance that a damage or loss event occurs.

(e) If a damage or loss event occurs the economic loss is obtained by sampling a uniform probability distribution between zero and the total cargo value.

(f) It is assumed that due to the lack of perfect scheduling knowledge the day the project will actually be ready to perform the module crane lifts is subject to a uniformly distributed uncertainty of ± 4 days centered about the projected date.

Additional simulations were run including the effects of weather forecasting. For one set an assumption was made that an 80% reliable 24 hour forecast was available. If that forecast predicted a time between gales greater than 24 hours then the tow proceeded, otherwise it waited one more storm cycle and checked the next forecast. Another model with a 64% reliable 48 hour forecast was similarly used.

The conclusions of this study were firstly that a five-day early departure from Seattle seemed a reasonable approach. This provided for some waiting time at Cape Spencer and uncertainty in the actual date for the crane lifts. Taking into account the four day trip from Seattle to Cape Spencer and the three day Gulf crossing, a Seattle departure date 12 days prior to the scheduled crane lift was recommended.

We should note that the effect of forecasting did show a improvement in the safety of the tow, but the economic drivers were the towing and crane costs, so the principal guiding element regarding departure from Cape Spencer was the judgment and experience of the tug operator.

As a point of interest the tows departed in mid-November and arrived at Cook Inlet ready for installation 8 days later with no damage or delay.

CONCLUSION

A key element in meeting the demands of current ocean towing and harbor/ship assist opportunities is to properly match tugs and tows to effectively utilize the capabilities of the towing vessels. Modern engineering methods coupled with a varied fleet can provide for a well planned, safe, and economic towing operation.

Selection of tugs for ocean and coastwise service using predictions of net towrope pull of the tug and predicted resistance characteristics of the tow can be used to estimate trip time, average speed and fuel consumption. Together with information from previous similar tows and the judgement of experienced Masters, these techniques can be used to reduce business and voyage risk.

As outlined in this paper, modern probabilistic techniques applied to climatological data can be added to the tow evaluation as appropriate to make decisions and aid in risk assessment. New techniques and analysis tools are continually being developed so that tug and tow characteristics can be combined with route and weather information to measure and evaluate overall economic and risk parameters of a particular voyage. Unique tows of substantial economic value demand the application of sophisticated techniques; and in today's competitive environment, many tows justify this approach.

Underwriters and surveyors benefit from use of these techniques in that expected performance of tugs can be evaluated in a direct way. The information on tug performance over the whole speed range, evaluated by an experienced surveyor, can be used to ensure that reasonable margins against extreme events have been provided.

Harbor tug performance characteristics have been widely discussed for many years and the body of knowledge that has been developed can be used by operators to evaluate the size, type and number of tugs for a particular operation. The discussion in this paper is an acknowledgement that analysis and rational evaluation of harbor and ship assist operations is a beneficial supplement to the experienced operator in selecting and deploying tugs for particular port and harbor operations.

ACKNOWLEDGEMENTS

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